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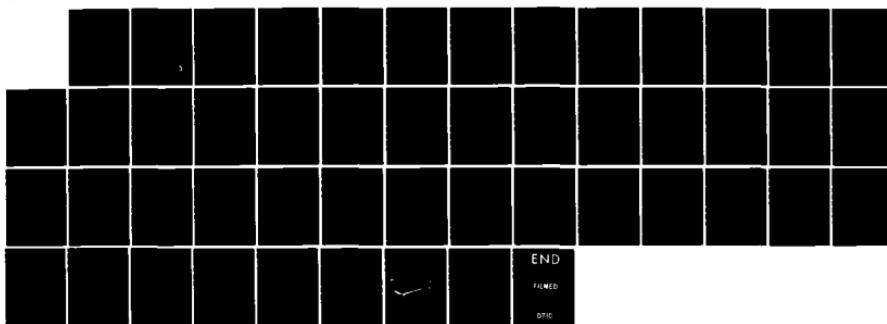
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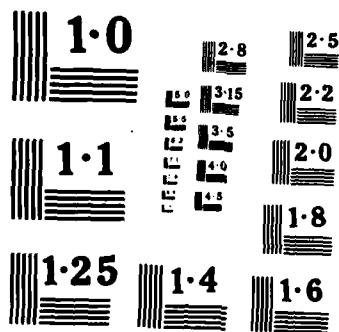
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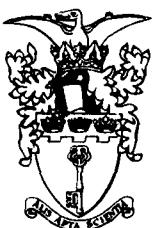
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A TEN CHANNEL TEMPERATURE CONTROLLER

by

D. H. Lister

May 1984

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Procurement Executive, Ministry of Defence
Farnborough, Hants

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ROYAL AIRCRAFT ESTABLISHMENT

Technical Memorandum P 1026

Received for printing 25 May 1984

A TEN CHANNEL TEMPERATURE CONTROLLER

by

D. H. Lister

SUMMARY

A modular ten channel temperature controller has been designed for use with modestly rated loads (<600 W). Versions using thermocouple and platinum resistance thermometer temperature sensors have been built and their performance characteristics determined. An option for driving higher power loads is also available.

Additional keywords: Schematic diagrams; measurement; assembly; Thermocouples; GPO B7; C

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LIST OF CONTENTS

	<u>Page</u>
1 INTRODUCTION	3
2 DESIGN AIMS	3
3 DESIGN AND CONSTRUCTION	4
3.1 Measurement and control module	4
3.1.1 The basic circuit	4
3.1.2 Temperature sensor options	5
3.1.3 Circuit board design	6
3.2 Cold junction compensation module	6
3.3 Temperature indicator module	6
3.4 Power supply module	7
4 ASSEMBLY	7
5 COMMISSIONING	7
6 PERFORMANCE	8
7 CONCLUSIONS	8
Acknowledgment	9
Appendix A Operation of controller with loads rated >2.5 A	11
Appendix B Measurement and control module pcb - variations between issues	12
Appendix C Pcb changes to accommodate sensor changes	13
Appendix D Measurement and control module - edge connections to pcb	14
Appendix E Cold junction compensation module - edge connections to pcb	15
Appendix F Power supply module - plug/socket connections	16
Appendix G Chassis connectors	18
Appendix H Components list	19
Appendix J Commissioning procedures	26
Tables 1 and 2	30
References	31
Illustrations	Figures 1-16
Report documentation page	inside back cover

1 INTRODUCTION

Measurement of the chemical constituents in combustion processes usually involves the acquisition of a sample and its transport through a sample transfer line to suitable measurement instrumentation. A prime requisite is to ensure that the sample composition remains unchanged from the point of acquisition through to the measurement system. Amongst other things, this entails maintaining the sample at a controlled temperature in the region 150-200°C.

Sample transfer lines typically are 30-100 ft long, often passing through different ambient temperature regimes in the length. Furthermore, the analysis system includes valves and filters of various shapes and sizes. Electric tape heaters are commonly used as the heating medium with thermocouples or platinum resistance thermometers as the temperature sensors. In a typical system it is not realistic to control the temperature of the system from one sensor input and many heaters and controllers are required if proper temperature control of the system is to be achieved.

Installation of a new gas sampling and analysis system in the Plant House (Cubicle C4B) in 1981 generated the need for 15-20 temperature controllers. The space available for these controllers was limited and ideally a multi-channel 19 inch rack mounted system would be preferred. A market survey indicated that almost all the commercial equipment was ruled out on size grounds; the remainder provided only relatively crude on/off relay switching - sometimes with the option of zero voltage switching through the addition of external components. Another consideration was the rapid rate of obsolescence of commercial designs and the potential difficulty of obtaining spares in a few years time.

Some expertise had been obtained with the design and build of a multi-channel temperature control unit for the first NGTE emissions van¹. While this was a platinum resistance thermometer (PRT) sensor based system and as such was not directly applicable for thermocouple sensors, the core circuitry, incorporating a zero voltage switch, had proved highly reliable. It was decided therefore to capitalise on this experience and build, in-house, a modular multi-channel unit. A number of these units could be used to provide the requisite total of temperature controllers for a given installation.

Initially two ten channel units, operating from thermocouple sensors, were built, commissioned and documented². Since then eight more units using PRT sensors have been manufactured. Operational experience gained with these units over the last 3 years, coupled with requirements to control either modestly rated loads (up to 600 W) or higher power loads (up to 2 kW) from the same unit, have led to some design changes which have now been incorporated into all the multi-channel temperature controllers.

This Memorandum describes the revised design, build and performance of the ten channel temperature controller.

2 DESIGN AIMS

These were as follows:

modular, multi-channel unit in a standard 19 inch rack
load rating 2A per channel: total load of unit 10A

3 DESIGN AND CONSTRUCTION

The design aims have been achieved in a controller which consists of

- (a) ten independent measurement and control modules;
- (b) a common cold junction compensation module (for controllers using thermocouple sensors), used in conjunction with an isothermal junction box for terminating compensated thermocouple cables;
- (c) a ten channel, switch selectable temperature indicator module;
- (d) a common power supply module.

Schematic diagrams of the controller are given in Figs 1 and 2. The diagram for the thermistor sensor based controller is very similar to that for the PRT based controller - two wire instead of four wire sensor connection - and no separate diagram is given. Details of the design are as follows.

3.1 Measurement and control module

3.1.1 The basic circuit

The circuit common to all the sensor options is based on a Texas Instruments zero voltage switch, type TL 440CN, and is shown in Figs 3 and 4. This switch is a combination threshold detector and zero crossing trigger intended primarily for ac power control applications. It allows a triac to be fired when the ac input signal crosses zero volts, thereby minimising undesirable electromagnetic interference. In this way, the load utilises full cycles of the ac waveform as opposed to partial cycles typical of SCR phase control power circuits.

The TL 440CN includes a zero voltage detector, a differential amplifier that can be used in conjunction with a resistance bridge to sense changes in the parameter being controlled, the active elements of a sawtooth generator and an output section. Also included are resistors which may be used as a voltage divider for the reference side of the resistance bridge.

In practice, these internal resistors have been linked and used to provide a reference voltage to the differential amplifier. The switch has been wired as a proportional controller using the sawtooth generator. The proportional bandwidth is determined by $R22/R23$ and details are given in Table 1.

The load switching device is either a triac coupled to the control circuitry through an opto-isolator with discrete components (Fig 3), or in the latest issue (Fig 4), an integrated opto-isolated solid state relay (SSR).

The triac or SSR is rated at 2.5 A. For control of higher power loads, the output of the zero voltage switch is made available as an open collector transistor drive for triggering of an external opto-isolated SSR of the requisite power rating. Details of this option are given in Appendix A.

Electrical isolation of the control circuitry from the load has been achieved by:

- (a) operating the zero voltage switch on dc and coupling its output via an opto-isolator.
- (b) Deriving the ac waveform fed to the zero crossing detector from an isolating transformer.

3.1.2 Temperature sensor options

Three alternative sensor input systems are available, namely thermistor, thermocouple and platinum resistance thermometer sensors.

(a) Thermistor sensor (Fig 5)

The thermistor, balance potentiometer (temperature set point adjustment) and internal resistors of the zero voltage switch are wired as a bridge across the inputs of the differential amplifier section of the switch to sense the change in resistance of the thermistor with temperature. The thermistor must have a negative temperature coefficient and a resistance of $< 10 \text{ k}\Omega$ at the control temperature.

(b) Thermocouple sensor (Fig 6)

With this type of sensor, the temperature sensitive arm of the bridge is replaced by an amplifier circuit. The input from the thermocouple is connected to a high quality differential input thermocouple amplifier (Ancom type 15TC-4) and summed with the input from an external cold junction compensation circuit (section 3.2). The gain is set to give an output sensitivity of $10 \text{ mV}/^\circ\text{C}$. (In the present circuit, R3 and RV4 are chosen for the gain requirements of Ni-Cr/Ni-Al thermocouples, although other thermocouple types could be used in conjunction with different resistor values.) The amplified output drives a temperature indicator circuit (section 3.3) and is also buffered and summed with the set point adjustment input before being fed to the zero voltage switch. The set point range can be adjusted by suitable choice of the resistors R15, RV16 and R17.

(c) Platinum resistance thermometer (PRT) sensor (Figs 7 and 8)

A PRT is a temperature sensitive device having a small, highly stable positive temperature coefficient, which is highly reproducible from one device to another. The type used here is to BS 1904, 100Ω at 0°C , 38.5Ω fundamental interval. In this application it is used in a bridge circuit across the inputs of a differential amplifier (not the one in the TL 440CN) with the gain set to give an output sensitivity of $10 \text{ mV}/^\circ\text{C}$. The output drives the temperature indicator circuit (section 3.3) and is also buffered, summed with the set point adjustment input and fed to the zero voltage switch.

The bridge and amplifier circuit is built onto a printed circuit board (pcb) which has been designed as a plug-in unit, pin compatible with the Ancom thermocouple amplifier. Issues A and B of the pcb differ only in the spacing of components.

3.1.3 Circuit board design

The circuit board has been laid out to incorporate the basic circuit and all of the sensor options by selection of movable links and a minimal number of component changes. The design has been translated into a pcb. Differences in issues of pcb are listed in Appendix B. The pcb is assembled with a front panel carrying a fuse, indicator lamp and set point adjustment potentiometer to form a 1 inch wide module. Figs 9 to 11 show the layout and component locations.

Details of the circuit board component and wiring changes required to accommodate changes of sensor are given in Appendix C. Edge connections to the pcb are listed in Appendix D.

3.2 Cold junction compensation module

The voltage generated by a thermocouple is proportional to the temperature difference between the hot junction (the tip) and the cold junction - often called the Reference junction.

Variation in the temperature of the cold junction will result in an apparent change in the temperature being measured. Therefore, for accurate control and measurement, it is necessary that the cold junction is either maintained at a suitable fixed temperature - usually 0°C , or allowed to vary in temperature and a compensation applied. In the present design the second approach has been adopted. The circuit is given in Fig 12.

The thermocouple sensor connections are run to an isothermal box as thermocouple wire and come out as copper/copper wire to the thermocouple amplifier. The temperature within the box is sensed by a PRT feeding a resistance bulb conditioner (Ancom 15RP-3) which is adjusted to give an output of $10 \text{ mV}/^{\circ}\text{C}$. This signal is fed to each of the thermocouple amplifiers in parallel and summed with the thermocouple signal to provide an output compensated for deviations of the cold junction temperature from 0°C , ie the amplifier output is a function of the sensor temperature in degrees Centigrade.

The circuit is built onto a plug-in stripboard and assembled with a front panel to form a 1 inch wide module. Pcb connection details are given in Appendix E.

3.3 Temperature indicator module

The output from either the thermocouple amplifier or the PRT bridge/amplifier is $10 \text{ mV}/^{\circ}\text{C}$. This is fed to an indicator circuit (Fig 13) consisting of a multi-way selector switch and an analogue meter in series with range setting resistors. With the meter ranged to read $0-300^{\circ}\text{C}$, the resolution is 5°C . More precise measurements may be made either by expanding the meter scale by correct choice of RV32/R33 and offsetting the meter zero by RV35, or via the output sockets provided using an external digital voltmeter. The circuit is built onto a 2 inch wide front panel.

3.4 Power supply module

Low voltage dc supplies are needed for powering the various amplifiers, the resistance bulb conditioner and the zero voltage switch. The last of these also requires a low voltage ac supply to the zero crossing detector.

The requirements are:

- (a) +15 V dc at 250 mA } for amplifiers, temperature indicator circuit and
- (b) -15 V dc at 150 mA } resistance bulb conditioner
- (c) -12 V dc at 100 mA } for zero voltage switch.
- (d) 20 V ac 6 Va

The purpose of using a zero voltage switch is to ensure that the mains voltage is switched near zero volts to minimise undesirable electromagnetic interference. Since the sense voltage for the switch is not the line voltage but is derived from a transformer, it is important that the secondary waveform is in phase with the primary waveform. The small transformers commonly available have unacceptable waveform characteristics and it was decided to use one good quality transformer to provide the basis of all the low voltage requirements. The complete circuit of the power supply unit is shown in Fig 14 and the circuit board layout in Fig 15. The transformer drives three diode rectifier bridges which feed fixed voltage monolithic voltage regulators to provide ± 15 V and -12 V dc. The ac voltage for the zero voltage switch is taken directly from the transformer secondary. The monolithic voltage regulators are mounted on a heat sink bolted to the rear of the main chassis, while the transformer and the remainder of the regulator circuits are built into a 4 inch wide screened case. Also included in the case is a power relay used to supply line voltage to the various loads being controlled via the measurement and control module (section 3.1). Details of the connections to the module are given in Appendix F.

4 ASSEMBLY

All the modules are housed in a standard 19 inch wide rack and cabinet, 5.25 inches high \times 10 inches deep. All connections are made to the rear panel and these are listed in Appendix G. A photograph of a completed unit is shown in Fig 16. One multi-way connector per channel is used for the PRT or thermistor sensors and load connections. For the thermocouple sensor version, the sensor inputs are interfaced via a multi-channel isothermal junction box, while the loads are connected individually to the controller.

A complete list of components is given in Appendix H.

5 COMMISSIONING

The controller requires initial adjustment of the cold junction compensation module, the thermocouple amplifier or PRT bridge amplifier in the measurement and control module and the temperature indicator module before the system is ready for use. The set point temperature control is adjusted during use. The procedure for carrying out all these adjustments is given in Appendix J.

6 PERFORMANCE

The performance of the controller will be influenced to a certain extent by the nature of the load and its matching to the controller. Typically, however, the ten channel control unit will be used in conjunction with heated sample line sections. Thus for the purpose of checking the units performance, three channels of a unit were connected to 3.5 m rigid sample line sections (~220 W each) of the type used with the Pyestock mobile emissions measurement facility. The proportional bandwidth of the controllers was $\sim 10^{\circ}\text{C}$. The line temperatures were monitored using PRT sensors built into the sections and recorded, either using a data logger or a chart recorder. The following performance aspects were evaluated.

(a) Stability

For this test, the supply voltage and ambient temperature were maintained reasonably constant (± 2 V ac, $\pm 1^{\circ}\text{C}$).

After warm up and equilibration, the temperature stability was monitored over a period of 2 hours. The temperature variations were less than $\pm 0.3^{\circ}\text{C}$ on all channels.

(b) Control point repeatability

A series of checks, over a period of several days, on the equilibrium temperatures attained by the sample line sections were carried out. Between each check, the lines were switched off for a period which ranged from 30 minutes up to several days. The temperatures attained are listed in Table 2. Day to day repeatability was within 1°C .

(c) Effect of supply voltage variation

The ac voltage supplied to the controllers and sample lines was varied over the range 230-270 V and at each setting sufficient time was allowed for restabilisation to see whether these changes had a noticeable effect on the monitored temperature. Tests were performed at set point temperatures of 100°C and 180°C . Effects were not significant ($0.011^{\circ}\text{C}/\text{volt}$ at 100°C and $0.025^{\circ}\text{C}/\text{volt}$ at 180°C). It should be noted that if it was necessary to use a larger bandwidth in the controller, these figures would also increase (roughly in proportion to the bandwidth increase).

(d) Effect of ambient temperature variation

The environmental temperature of the heated sections was varied from 0-20 $^{\circ}\text{C}$ and effects on monitored set point temperature evaluated. Changes were negligible $<0.2^{\circ}\text{C}$ both at 100°C and 180°C set points. Again it should be noted that increase in proportional bandwidth would adversely affect this characteristic.

The controller itself also seemed unaffected by ambient temperature changes.

7 CONCLUSIONS

A modular ten channel temperature controller has been designed and both PRT and thermocouple sensor based systems built and tested. Features of the controller are:

- (i) zero voltage switching of the loads
- (ii) electrical isolation of the load from the control and measurement circuit

- (iii) control range ≥ 0 to 250°C
- (iv) indication of the control temperatures
- (v) option of thermocouple, PRT or thermistor sensor
- (vi) stability better than $\pm 0.3^{\circ}\text{C}$ over a period of ~ 2 hours
- (vii) day to day repeatability within 1°C
- (viii) effect of supply voltage variation on control temperature is negligible
- (ix) effect of ambient temperature changes on control temperature is negligible.

Acknowledgment

The author would like to thank Mr D.A. Kilpatrick for the helpful discussions and advice which he has freely given during the development of this system.

Appendix AOperation of controller with loads rated >2.5 A

The unit provides, on each channel, an open collector transistor drive (12 V, 100 mA maximum) for external control purposes. Optically isolated zero voltage switching solid state relays (SSR) provide a means of controlling high rated loads (up to at least 40 A) with minimum electrical interference and electrical isolation of the load from the control circuitry.

Operation is implemented as follows:

- (a) On measurement and control module, either
 - (i) remove opto isolator A6 - Issues A-D, or
 - (ii) rearrange links - remove 2, make 1 and 3 - Issue E.
- (b) Connect control lines (Appendix G) from six-way DIN socket to SSR control inputs
 - (i) pin 6 to negative input of SSR
 - (ii) channel drive pin to positive input of SSR.
- (c) Connect external ac power
 - (i) L through appropriate fuse to SSR line input
 - (ii) SSR load output to load.
 - (iii) N to load.
- (d) Connect temperature sensor to controller (Appendix G)
 - PRT or thermistor sensor to Plessey connector
 - thermocouple sensor to 25 way 'D' connector via isothermal box.

Note: Indicator lamp on controller module is inoperative in this mode. An external indicator must be provided in parallel with the load.

Appendix B

MEASUREMENT AND CONTROL MODULE PCB - VARIATIONS BETWEEN ISSUES

Issue A October 1980 (production: 40 by Integrated Electronics Limited (IEL)).
Original production, though not as designed due to loss of track pieces from artwork master between checking of master and production of pcb. Errors corrected, after assembly, by wire links on track side of pcb. Tracks for thermistor sensor connections not laid out as requested, but accepted for this issue. Small design error (R19/R20 connections to TL440CN) unnoticed until testing (after artwork retouched to replace missing track pieces).

Issue B October 1980 (production: nil).
Retouch of artwork to replace missing track pieces.

Issue C May 1981 (production: 40 by IEL).
Thermistor sensor connecting tracks and other tracks re-routed. Design error of Issue A corrected, but further minor error introduced in same area. Corrected after assembly by addition of extra pin.

Issue D January 1983 (production: 30 by White and Nunn).
Design error of C corrected. Provision made for driving external SSR (link from R26/TR1 to edge connector pin 21).

Issue E January 1984 (production: 20 by GB Electronics).
Redesigned to accommodate SSR (AII) instead of discrete component circuitry for load switching device and opto-isolator. Selection of on-board or external SSR via links.

Appendix JCOMMISSIONING PROCEDURES

Adjustments can be carried out, either with the rack removed from the case, or with the pcb's fitted to an extender board.

a) Cold junction compensation (CJC) module

- (i) Replace the PRT sensor with a standard resistance box.
Connect the output of the module to a DVM.
- (ii) Set $R = 100 \Omega$, adjust zero potentiometer until output is 0.000 V.
- (iii) Set $R = 138.5 \Omega$, adjust gain potentiometer until output is 1.000 V.
- (iv) Reconnect PRT sensor.

Unit is now set to give a linear output conditioned to 10 mV/ $^{\circ}$ C.

b) Thermocouple amplifier

- (i) With the CJC module adjusted as in (a)
connect a standard resistance box to the input of CJC module in place of the PRT sensor,
connect a millivolt source in place of the thermocouple at input to the measurement and control module,
connect the output of the measurement and control module to a DVM.
- (ii) Set $R = 100 \Omega (0^{\circ}\text{C})$ and mV source = 0.000 mV.
Adjust RV2, until output = 0.000 V.
- (iii) Set mV source for highest calibration temperature required.
Adjust RV4 for correct output (10 mV/ $^{\circ}$ C).
- (iv) Set mV source to 0.000 mV, check output = 0.000 V, readjust if necessary.
- (v) mV source at 0.000 mV, set $R = 119.4 \Omega (50^{\circ}\text{C})$.
Adjust RV1 until output = 0.500 V (50 $^{\circ}$ C).
- (vi) Reconnect PRT sensor to CJC module.
Reconnect thermocouple sensor.

This completes the internal adjustments. Set point adjustment is given under (f).

c) PRT bridge amplifier

- (i) Replace the PRT sensor with a standard resistance box.
Link lead compensation terminals.
Connect the output of the measurement and control module to a DVM.
- (ii) Set $R = 100 \Omega$, adjust RV2 until output = 0.000 V.
- (iii) Set R to correspond to the highest calibration temperature required.
Adjust RV4 for correct output (10 mV/ $^{\circ}$ C).

H.5 Chassis/cabinet

Item description	Comment
19 inch racking case 3 U high 10 inch deep	Vero
19 inch rack kit	Vero
guide location straps 0.5 inch pitch	Vero - 4 required
tapped strips 0.5 inch pitch	Vero - 4 required
card guides	Vero - 26 required
rear panel to drawing SK 120995	RAE manufacture
fixing brackets to drawing SK 120996	RAE manufacture
pcb edge connector 0.1 inch pitch single side, 43 way	RS Components 466-999 11 required
module connector - 24 way socket	RS components 467-015
mounting screws M3 x 6 mm	26 required
DIN 6 way chassis socket	2 required
'D' sub-miniature 25 way socket	
6 way fixed socket (Plessey type)	10 required
LMF/1/40043/32	Lane Electronics

H.4 Power supply module

Part No.	Description	Value	Comment
-	pcb		
R36	resistor, 0.5 W, tol \pm 2%, metal oxide	4K7	
R37	" " " " "	4K7	
R38	" " " " "	4K7	
R39	" " " " "	1K2	
R40	" " " " "	1K2	
R41	" " " " "	1K0	
C6	capacitor, electrolytic 63 V	4700 μ F	
C7	" " 63 V	4700 μ F	
C8	" " 35 V	220 μ F	
C9	"	0.47 μ F	
C10	"	0.47 μ F	
C11	"	4.7 μ F	
D4-9	diode IN4002		Six required
A8	monolithic fixed voltage regulator type 7815	+15 V	
A9	monolithic fixed voltage regulator type 7915	-15 V	
A10	monolithic fixed voltage regulator type 7912	-12 V	
L2	240 V ac, neon indicator lamp		
L3-5	led indicator, 6 mm diameter		Three required
T1	transformer 240 V primary, secondary 20 V 0.5 A; 20 V 0.5 A		RS Components 207-166
S2	switch SPST 1 A rating		
S3	power relay DPDT 10 A rating 230 V ac coil		RS Components 348-762
-	base for above		401-706
F2	20 mm fuseholder		509-333
-	4 inch wide module		509-361
-	screening kit		509-377
-	connector mounting plate		467-009
-	module connector - 24 way plug		467-576 (2 off)
	pcb plug, straight - 5 way		468-096 (2 off)
	pcb plug, 90° - 5 way		467-627 (4 off)
	cable shell - 5 way		467-598 (14 off)
	crimp terminal		543-484 (2 off)
	cable tie and base		
	heat sink, 4°C/W		401-497

H.2 Cold junction compensation module

(only required for thermocouple sensor versions)

Part No.	Description	Value	Comments
-	43 way single sided stripboard 114 x 203 x 1.6 mm: 0.1 inch pitch		
RV29	Platinum resistance thermometer to BS 1904 38.5 Ω fundamental interval sheathed version, type E13050	100R @ 0 C	Rosemount Engineering
RV30	1/2 inch, 20 turn trimmer	50K	
RV31	1/2 inch, 20 turn trimmer	50K	
A7	Resistance bulb conditioner, type 15RP3		Ancom
-	1 inch wide front panel assembly, 3 U high		Vero
-	connector jack part no. 450-3704-01-03-00		Nine required Cambion Electronic Products

H.3 Temperature indicator module

Part No.	Description	Value	Comments
-	pcb		
RV32	1/2 inch, 20 turn trimmer	*	
R33	resistor, 0.5 W, tol ± 2%, metal oxide	*	
RV34	1/2 inch, 20 turn trimmer	1K	
RV35	1/2 inch, 20 turn trimmer	1K	
D3	diode OA202		
M1	meter, 45 x 45 mm, 0-100 μA fsd		
S1	1 pole 12 way rotary switch Elma Radiation type 01-1120		STC Electronic Services
-	stator, figure dial and knob for above		
-	4mm wander plug socket		two required (red/black)
-	2 inch wide front panel assembly, 3 U high drilled to drawing SK 120998		Vero

Items marked * are selected according to temperature range required (see Appendix J(e) for details of appropriate values)

(e) PRT sensor input option

Part No.	Description	Value	Comments
-	pcb WN 2058 - Issue A or B		
RV2b	1/2 inch, 20 turn trimmer	500R	
R3b	resistor, 0.5 W, tol ± 2%, metal oxide	100K	
RV4	1/2 inch, 20 turn trimmer	50K	
R5	resistor, 0.25 W, tol ± 2%, metal film/oxide	6K2	
R6	resistor, 0.25 W, tol ± 2%, metal film/oxide	6K2	
R7	resistor, 0.25 W, tol ± 2%, metal film/oxide	100R	
R8	resistor, 0.25 W, tol ± 2%, metal film/oxide	10K	
R9	resistor, 0.25 W, tol ± 2%, metal film/oxide	10K	
R10	resistor, 0.25 W, tol ± 2%, metal film/oxide	120K	
R11	resistor, 0.5 W, tol ± 2%, metal oxide	10K	
R12	" " " " "	10K	
R13	" " " " "	10K	
R14	" " " " "	10K	
R15	" " " " "	*	
RV16	1/2 inch, 20 turn trimmer	1K	
R17	resistor, 0.5 W, tol 2%, metal oxide	*	
R18	" " " " "	10K	
R19	" " " " "	10K	
R20	" " " " "	10K	
C1	capacitor, electrolytic 25 V	100 μF	
C2	capacitor, polycarbonate 160 V	0.47 μF	RS Components 114-008
A2	8 pin dill socket		
A3	operational amplifier μA 741CP		
A4			
-	connector part no. 460-2970-02-03-00		10 required Cambion Electronic Products
-	terminal pins for 1.0 mm hole		Four required

Items marked * are selected on commissioning

(c) Thermocouple sensor input option

Part No.	Description	Value	Comments
RV1a	1/2 inch, 20 turn trimmer	5K	
RV2a	1/2 inch, 20 turn trimmer	10K	
R3a	resistor, 0.5 W, tol ± 2%, metal oxide	220K	
RV4	1/2 inch, 20 turn trimmer	50K	
R11	resistor, 0.5 W, tol ± 2%, metal oxide	10K	
R12	" " " " "	10K	
R13	" " " " "	10K	
R14	" " " " "	10K	
R15	" " " " "	*	
RV16	1/2 inch, 20 turn trimmer	1K	
R17	resistor, 0.5 W, tol ± 2%, metal oxide	*	
R18	" " " " "	10K	
R19	" " " " "	10K	
R20	" " " " "	10K	
A1	thermocouple amplifier 15TC4		Ancom
A3	8 pin dil socket operational amplifier μA 741CP		
A4	8 pin dil socket operational amplifier μA 741CP		
-	connector jack part no. 450-3704-01-03-00		10 required Cambion Electronic Products
-	terminal pins for 1.0 mm hole		Four required

Items marked * are selected on commissioning

(d) Thermistor sensor input option

This requires only RV16 (as specified above).

(b) Basic circuit (Issue E)

Part No.	Description	Value	Comments
-	pcb - JM 3306 - Issue E		
R21	resistor, 0.5 W, tol \pm 2%, metal oxide	10K	
R22	" " " " "	*	
R23	" " " " "	8K2	
R24	" " " " "	39K	
R25	" " " " "	10K	
R42	" " " " "	100R	
C3	capacitor, disc ceramic 30 V	100 nF	
C4	capacitor, electrolytic, 25 V	22 μ F	
C12	capacitor, polyester, 250 V ac	100 nF	
TR1	transistor, 2N 3906		
A5	14 pin d1l socket zero voltage switch TL 440CN		Texas
A11	2.5 A opto isolated solid state relay		Hamlin 7562
L1	240 V ac neon indicator lamp		
F1	20 mm fuseholder		
-	1 inch wide front panel assembly, 3 U high drilled to drawing SK 120997		Vero
-	panel mounting bush for $\frac{1}{2}$ inch trimmer		
-	insulating boot for fuseholder		
-	terminal pins for 1.0 mm hole		Eight required

Items marked * are selected on commissioning

Appendix HCOMPONENTS LISTH.1 Measurement and control module

(a) Basic circuit (Issues A-D)

Part No.	Description	Value	Comments
-	pcb - JM 3306 - Issue A-D		
R21	resistor, 0.5 W, tol \pm 2% metal oxide	10K	
R22	" " " " "	*	
R23	" " " " "	8K2	
R24	" " " " "	39K	
R25	" " " " "	10K	
R26	" " " " "	390R	
R27	" " " " "	180R	
R28	resistor, 2W, tol \pm 5%, carbon film	22K	
C3	capacitor, disc ceramic, 30 V	100 nF	
C4	capacitor, electrolytic, 25 V	22 μ F	
C5	capacitor, electrolytic, 25 V	100 μ F	
D1	zener diode, BZX61	10 V	
D2	diode, IN4004		
TR1	transistor, 2N 3906		
TR2	triac, T2306D		RCA
A5	14 pin dil socket zero voltage switch TL 440CN		Texas
A6	8 pin dil socket opto isolator - RS 307-963		RS components
L1	240 V ac neon indicator lamp		
F1	20 mm fuseholder		
-	1 inch wide front panel assembly, 3 U high drilled to drawing SK 120997		Vero
-	panel mounting bush for $\frac{1}{2}$ inch trimmer		
-	insulating boot for fuseholder		
-	T05 heat sink, 35° C/W		
-	T05 mounting pad		
-	terminal pins for 1.0 mm holes		Four required

Items marked * are selected on commissioning

Appendix G
CHASSIS CONNECTORS

Connector	Pin	Function
Plessey 6 pin fixed socket	A B C D E F	sensor (PRT or thermistor) sensor lead compensation (PRT only) load
'D' sub-miniature 25 way	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25	thermocouple, channel 1, positive " " 2, " " " 3, " " " 4, " " " 5, " " " 6, " " " 7, " " " 8, " " " 9, " " " 10, " no connection no connection PRT sensor of cold junction compensation module thermocouple, channel 1, negative " " 2, " " " 3, " " " 4, " " " 5, " " " 6, " " " 7, " " " 8, " " " 9, " " " 10, " no connection PRT sensor of cold junction compensation module
DIN 6 way sockets Channel numbers in () apply To left hand DIN socket Other numbers apply to right Socket (as viewed from rear)	1 2 3 4 5 6	external SSR drive, channel 1 (6) " " " " 2 (7) " " " " 3 (8) " " " " 4 (9) " " " " 5 (10) -12 V

POWER SUPPLY MODULE - PCB CONNECTIONS

Socket	Pin	Connection
A	1	Earth
	2	-
	3	20 V ac
	4	-
	5	20 V ac
B	1	Indicator L3(+)
	2	Indicator L4(-)
	3	Indicator L5(-)
	4	Indicators L3(-), L4(+), L5(+)
	5	-
C	1	module connector, pin 21
	2	-
	3	module connector, pin 24
	4	-
	5	module connector, pin 23
D	1	module connector, pin 10
	2	-
	3	module connector, pin 12
	4	-
	5	module connector, pin 11

Appendix FPOWER SUPPLY MODULE - PLUG/SOCKET CONNECTIONS

<u>Pin No.</u>	<u>Plug connections (module)</u>	<u>Socket connections (chassis)</u>
1 2 3	Fuse F2 power relay S3	240 V ac line
4 5 6	transformer primary power relay S3	240 V ac neutral
7 8 9	module case transformer secondary c.t. pin 23	240 V ac earth chassis
10	pcb connector D1	heat sink, input of +15 V regulator
11	pcb connector D3	heat sink, input of -12 V regulator
12	pcb connector D2	heat sink, input of -15 V regulator
13 14 15	power relay S3	pin 2 of pcb edge connectors
16 17 18	power relay S3	pin 7 of pcb edge connectors
19	transformer secondary, 20 V	pin 12 of pcb edge connectors
20	NC	NC
21	pcb connector C1 (-12 V)	pin 18 of pcb edge connectors heat sink, output -12 V regulators pin 6 of DIN chassis sockets
22	pcb connector C3 (+15 V)	pin 29 of pcb edge connectors heat sink, output of +15 V regulator
23	pin 8	pin 31 of pcb edge connectors heat sink, common of regulators
24	pcb connector C2 (-15 V)	pin 33 of pcb edge connectors heat sink, output of -15 V regulator

Appendix ECOLD JUNCTION COMPENSATION MODULE - EDGE CONNECTIONS TO PCB

<u>Pin No.</u>	<u>Connection</u>
22	PRT sensor
23	PRT sensor
25	output
29	+15 V dc
30	0
31	-15 V dc

Appendix DMEASUREMENT AND CONTROL MODULE - EDGE CONNECTIONS TO PCB

Pin No.	Function	Connection
2	240 V ac line	pin 13, psu module connector
4	load (high side)	pin F, Plessey chassis connector
7	240 V ac neutral	pin 16, psu module connector
9	load (low side)	pin E, Plessey chassis connector
10	thermistor i/p	pin A, Plessey chassis connector (Issue A pcb only)
12	20 V ac	pin 19, psu module connector
18	-12 V dc	pin 21, psu module connector
21	external SSR drive (positive)	DIN chassis connector
22	thermistor i/p	pin B, Plessey chassis connector (all Issues)
23	thermistor i/p	pin A, Plessey chassis connector (Issues C, D and E pcb)
25	*cold junction compensation **lead resistance compensation	pin 25, of cold junction compensation module pin C, Plessey chassis connector
27	*thermocouple i/p (positive) **PRT sensor	25 way chassis connector pin A, Plessey chassis connector
29	+15 V dc	pin 22, psu module connector
31	0 V	pin 23, psu module connector
33	-15 V dc	pin 24, psu module connector
35	amplifier o/p	temperature indicator circuit
37	polarisation slot of pcb	
39	*thermocouple i/p (negative) **PRT sensor and lead resistance compensation	25 way chassis connector pins B and D, Plessey chassis connector

* for thermocouple sensor version

** for PRT sensor version

While measurement and control modules may be reconfigured for operation with different types of sensors (Appendix C), chassis are hard wired for only one type of sensor input and would require significant alterations to permit use of a different sensor type.

Appendix CPCB CHANGES TO ACCOMMODATE SENSOR CHANGES

The change of use of an existing pcb will require changes in chassis connectors and in the connections between these and the pcb edge connectors as well as modifications to the pcb itself.

This Appendix lists only the modifications to the pcb which are required to accommodate the use of a different sensor. The other changes required may be derived from the listing in Appendices D and G.

C.1 Thermocouple → thermistor

- (a) Remove R19 and R20; remove amplifier 15TC-4.
- (b) Disconnect flying leads between set point adjustment potentiometer (RV16) and pcb. Reconnect potentiometer pins 1 and 2 in place of R20.

C.2 Thermistor → thermocouple

- (a) Reverse procedure listed in C.1.
- (b) Install any components not yet on the pcb.

C.3 PRT → thermistor

- (a) Remove R19 and R20; remove 'plug in'.
- (b) Disconnect flying leads between set point adjustment potentiometer (RV16) and pcb. Reconnect potentiometer pins 1 and 2 in place of R20.

C.4 Thermistor → PRT

- (a) Reverse procedure listed in C.3.
- (b) Install any components not yet on the pcb.

C.5 Thermocouple → PRT

- (a) Remove amplifier 15TC-4.
- (b) Install PRT bridge/amplifier plug in.
- (c) RV1: remove and install shorting link across positions of pins 2 and 3.
- (d) RV2: remove 10 K potentiometer and install 500 K potentiometer.
- (e) R3: remove 220 K resistor and install 100 K resistor.

C.6 PRT → thermocouple

- (a) Reverse procedure listed in C.5.

- (iv) Repeat steps (ii) and (iii) until both zero and gain is correct.
- (v) Reconnect PRT sensor.
Unlink lead compensation terminals.

This completes the internal adjustments. Set point adjustment is given under (f).

(d) Temperature indicator circuit

The output from the thermocouple amplifier or PRT bridge amplifier is 10 mV/°C.

The basic sensitivity of the analogue meter is 0-100 µA.

The meter is scaled 0-3 V (≡300°C) and 0-10 V (≡1000°C).

∴ for a 3 V input to give full scale deflection

$$\begin{aligned}
 R_{\text{total}} &= R_{\text{meter}} + RV32 + R33 \\
 &= \frac{3}{100 \times 10^{-6}} = 30 \text{ K } \Omega \\
 R_{\text{meter}} &= 1\text{K}8 \quad \therefore RV32 + R33 = 28\text{K}2
 \end{aligned}$$

Suitable values to allow for adjustment are:

$$RV32 = 10\text{K}, \quad R33 = 22\text{K}.$$

The temperature indicator switch positions are as follows:

- position 1-10 outputs of channels 1-10
- position 11 temperature monitor zero check
- position 12 temperature monitor fsd check.

Basic calibration:

- (i) Power up the controller.
- (ii) Connect a DVM to the output sockets of the temperature monitor.
- (iii) Set selector switch to position 11 and turn RV35 fully clockwise.
Adjust analogue meter to read 0 using screw on meter front panel.
- (iv) Set selector switch to position 12
adjust RV34 until DVM reads 3.00 V
adjust RV32 until analogue meter reads full scale.
- (v) mark meter scale 0-300°C.

Zero offset:

Measurement of a temperature outside the range 0-300°C may be made either by ranging the meter scale to read, say, 0-10 V, 0-1000°C (see scale range change procedure) or by offsetting the meter zero if a limited measurement range is more appropriate, eg to measure in the range 500-800°C.

- (i) Switch off power to the controller.
- (ii) Remove channel 1 pcb from chassis and set temperature monitor selector switch to position 1.
- (iii) Connect a voltage source to the output sockets of the monitor, set to 5.00 V.
- (iv) Adjust RV35 until analogue meter reads 0.
- (v) Set voltage source to 8.00 V. Meter should now indicate full scale. If not, adjust RV32 and repeat (iii) to (v).
- (vi) Disconnect voltage source, install channel 1 pcb and power up controller. Set selector switch to position 12.
- (vii) Adjust RV34 until meter reads full scale.
- (viii) Mark meter scale 500-800°C.

Scale range change:

Change of range requires changes in RV32 and R33 as follows:

<u>Scale change</u>	<u>Temperature range</u>	<u>RV32</u>	<u>R33</u>
× 0.33	1000°C	20K	91K
× 1	300°C	10K	22K
× 3	100°C	2K	6K8
× 5	60°C	1K	3K3 or 3K9

- (i) Connect circuit as in basic calibration (i).
- (ii) Set minimum of range using zero offset control as in previous sections.
- (iii) Set RV34 for given desired full scale reading at 10 mV/°C.
Adjust RV32 until meter reads full scale.
- (iv) Set RV34 for intermediate point on meter scale.
Check meter reads a correct corresponding value.
If in error, check the scale at several points and mark the meter scale appropriately.
- (v) Mark meter scale with appropriate temperatures.

Note: Thermocouple sensors have a non-linear response to temperature. Therefore over a wide range, non-linear scale marking would be correct. But for small ranges, *eg* 300°C, errors due to non-linear response are fairly small and can be neglected for this application, *eg* for a calibration correct at 200°C, any indicated measurement in the range 0-300°C is within 1°C of the true value.

This completes the adjustment of the temperature indicator circuit.

(e) Controller bandwidth setting

This is determined by a number of factors which are unique to individual experimental systems, *eg* the heater load being controlled, its matching to the thermal

requirements of the system, the temperature cycling which may be tolerated at the set point and the overshoot during warm up.

Basically, a narrow proportional band results in a fast warm up, with little change in set point temperature with duty factor (droop), but at the expense of likely overshoot during warm up and temperature cycling at the set point.

A wide proportional band gives a slower warm up, without overshoot or cycling but with droop (in a simple proportional control system).

The bandwidth should be determined experimentally with the individual system. However, as standard the control pcb is configured with $\sim 10^{\circ}\text{C}$ bandwidth.

(f) Set point adjustment

The set point range is determined by the resistors R15, RV16, R17. Suitable values for some selected ranges are:

Temperature range	R15	RV16	R17
0-300 $^{\circ}\text{C}$	3K3	1K	2K2
500-800 $^{\circ}\text{C}$	4K7	1K	1K
0-1000 $^{\circ}\text{C}$	12K	10K	1K5

If other ranges are required, then resistance values can be calculated by applying Kirchhoff's Law to R14, R15, RV16, R17 network (V at A3 input = ~ 0 V), knowing the voltages required at A3 output for the bandwidth set (Table 1).

To adjust the set point within the desired range, proceed as follows:-

(i) Connect the load and sensor to the measurement and control module. Monitor the temperature.

(ii) Switch on; indicator lamp on the front of the measurement control module should be lit. If not, turn set point adjustment control (RV16) clockwise until lamp lights.

(iii) Allow the system to warm up, adjusting the set point to give the desired temperature (clockwise for higher temperature, anti-clockwise for lower temperature).

This completes the set point adjustment.

Table 1
PROPORTIONAL BANDWIDTH SETTING

R22 (Ω)	R23 (Ω)	Bandwidth ($^{\circ}\text{C}$)	Voltage swing at A3 o/p at controller set point
0	8K2	0	0 V
100	"	7	-0.42 V to -0.35 V
200	"	14	-0.56 V to -0.42 V
400	"	26	-0.81 V to -0.55 V
600	"	37	-1.04 V to -0.67 V
800	"	47	-1.26 V to -0.79 V
1K	"	57	-1.47 V to -0.89 V

Table 2
CONTROL POINT REPEATABILITY

(a) Thermocouple sensor version

Date	Time	Temperature		
		CH1	CH2	CH3
20.5.81	pm	161.7	171.0	193.3
21.5.81	am	161.7	171.0	193.3
	pm	161.7	171.0	193.3
22.5.81	am	161.7	171.0	193.0
	pm	161.3	171.0	193.3
27.5.81	am	161.3	171.0	192.0*
	pm	161.5	171.0	193.0
29.5.81	pm	161.7	171.0	193.3

* poor thermocouple connection, when checked

(b) PRT sensor version

Date	Time	Temperature		
		CH1	CH2	CH3
24.1.84	pm	170.8	173.2	175.3
25.1.84	am	171.0	173.4	175.6
	pm	170.9	173.6	175.3
26.1.84	am	171.3	173.6	175.2
	pm	171.2	173.1	175.0
27.1.84	am	171.1	173.3	175.0
	pm	170.5	173.2	174.6
30.1.84	am	170.7	173.4	175.6
	pm	171.1	173.0	175.3
1.2.84	pm			

REFERENCES

<u>No.</u>	<u>Author</u>	<u>Title, etc</u>
1	D.A. Kilpatrick	A temperature control system using PRT sensors. Unpublished work at NGTE (1974)
2	D.H. Lister	A ten channel temperature controller. Unpublished work at NGTE (1981)

Fig 1

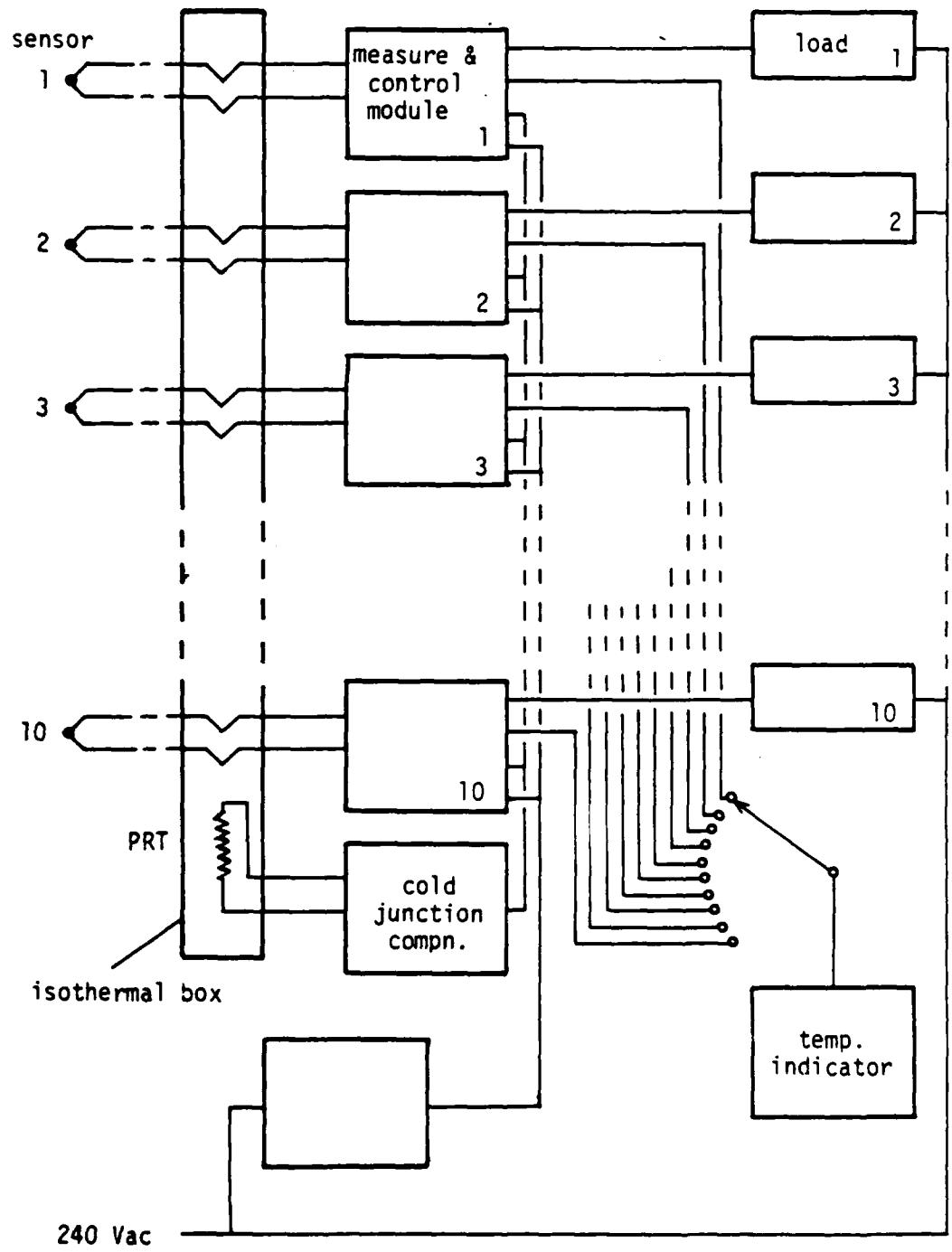


Fig 1 Schematic diagram of system using thermocouple sensors

Fig 2

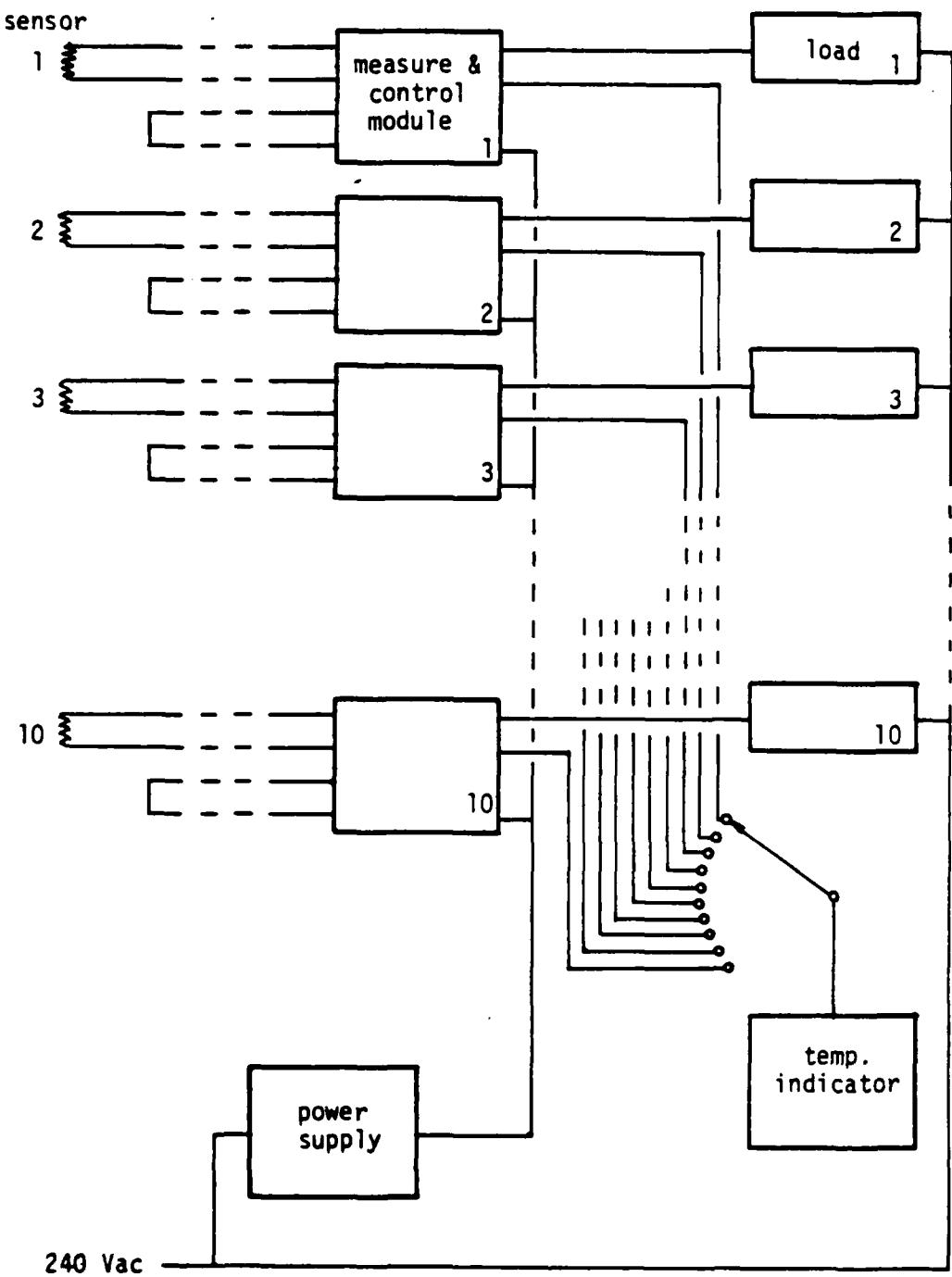


Fig 2 Schematic diagram of system using platinum resistance sensors

Fig 3

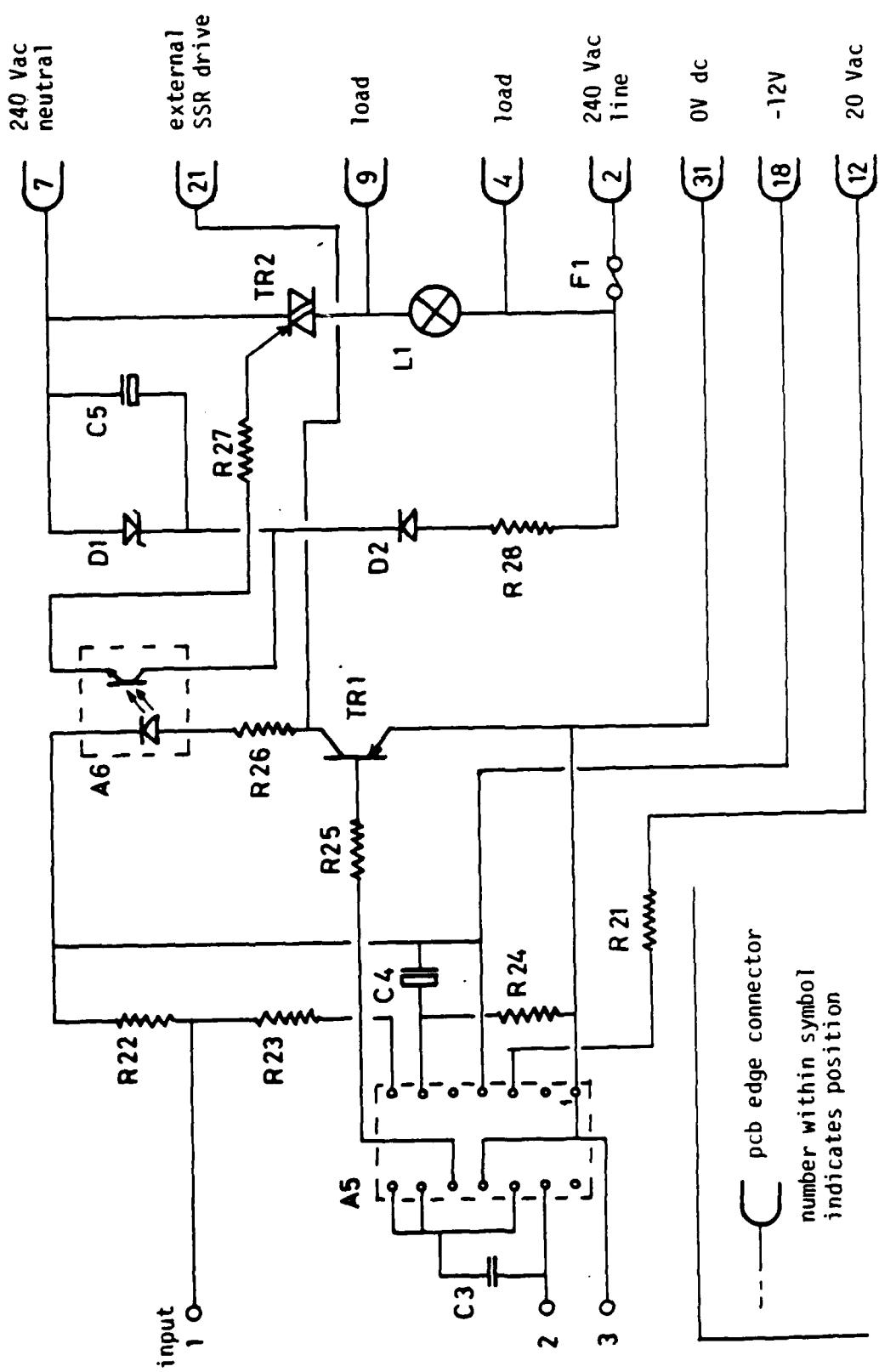


Fig 3 Basic circuit of controller - Issues A-D

Fig 4

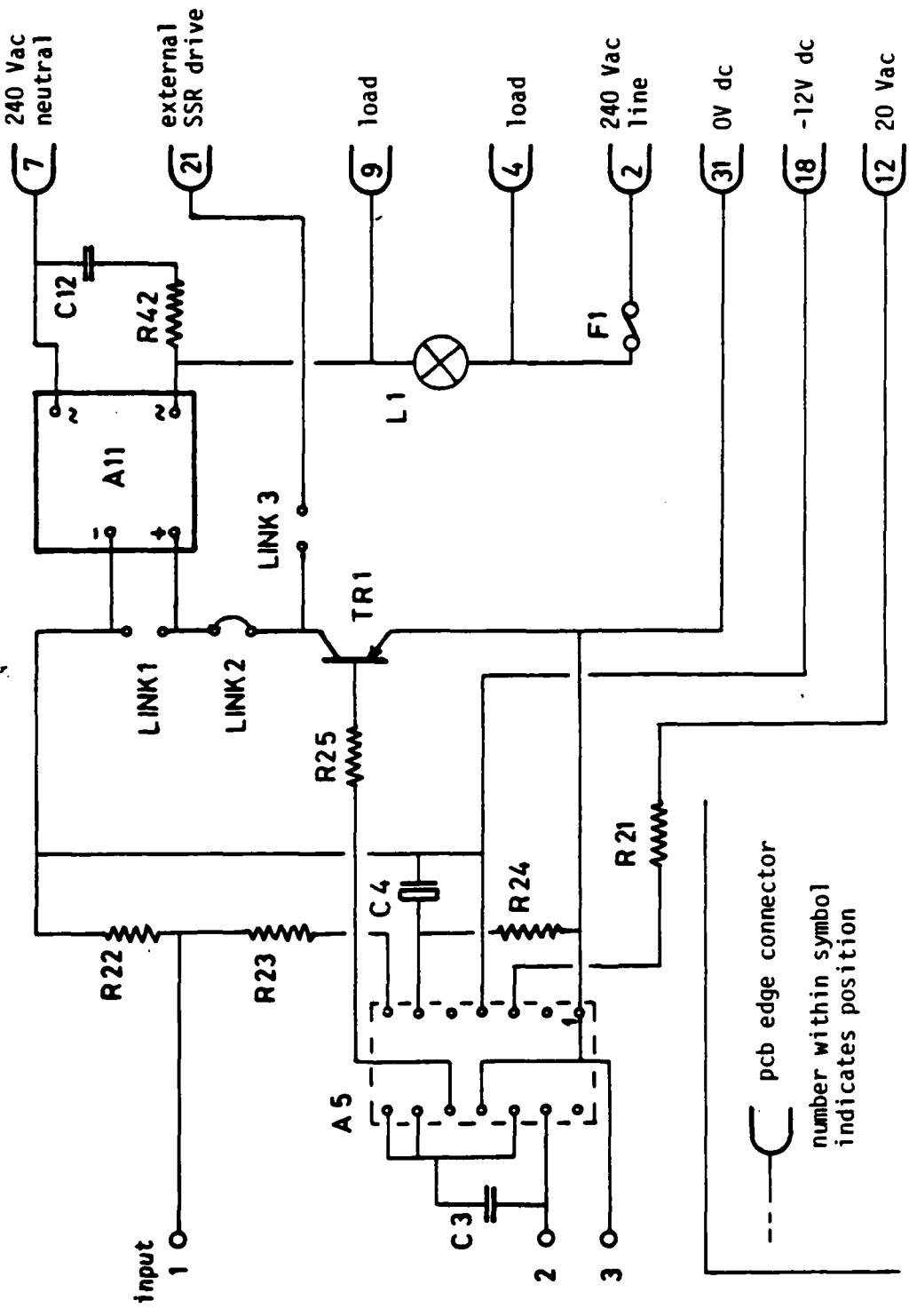


Fig 4 Basic circuit of controller - Issue E

Fig 5

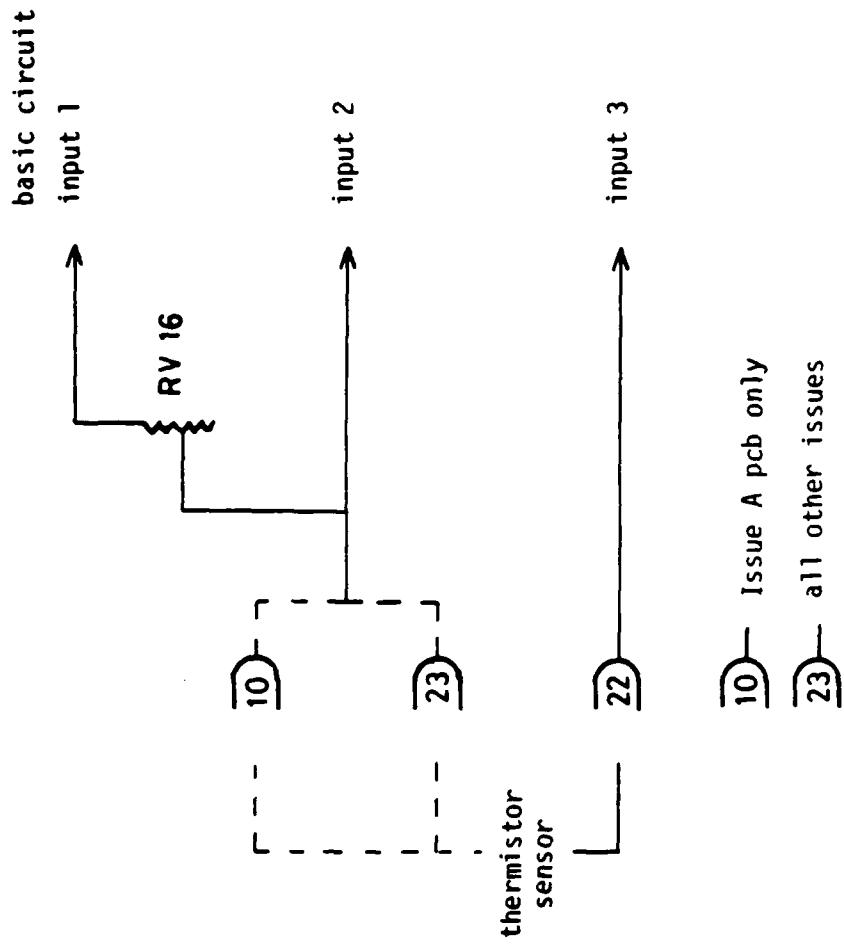


Fig 5 Input circuit for a thermistor sensor

Fig 6

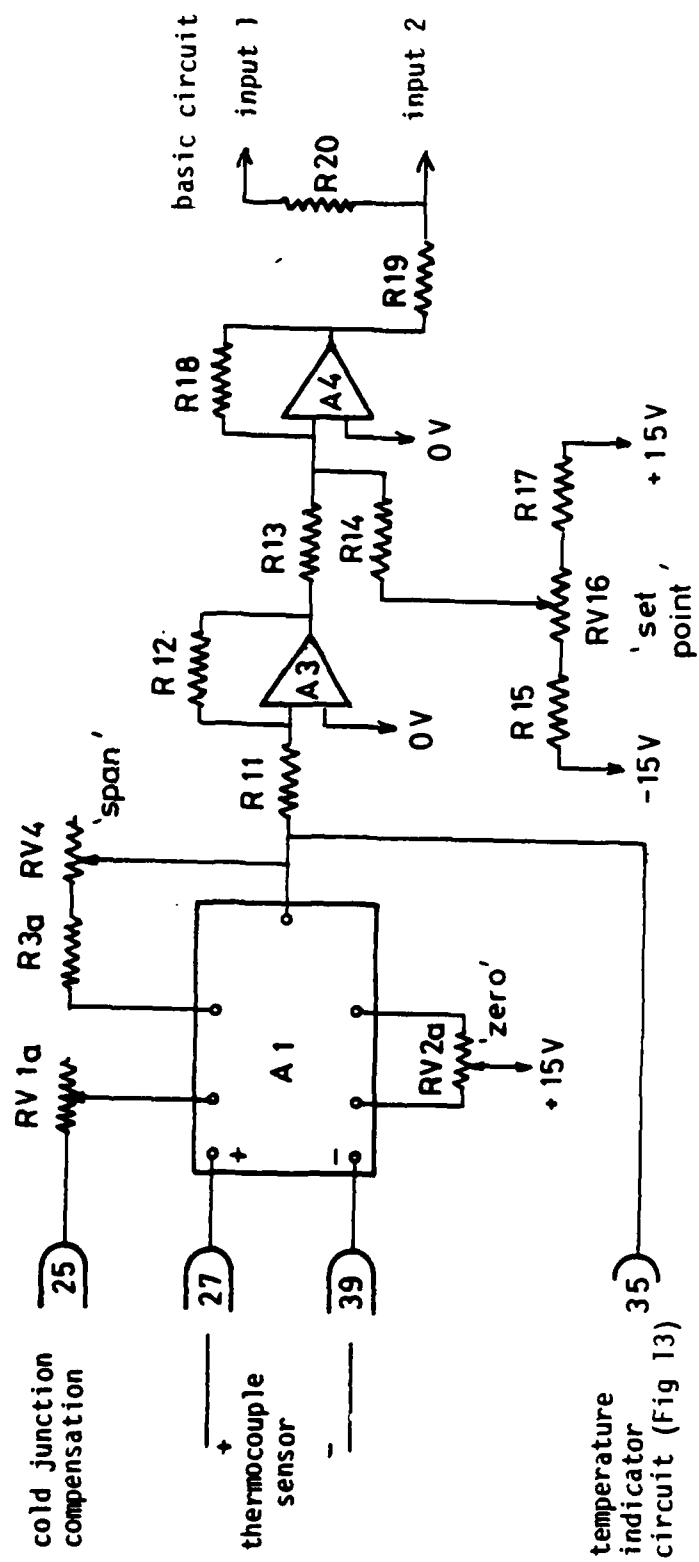


Fig 6 Input circuit for a thermocouple sensor

Fig 7

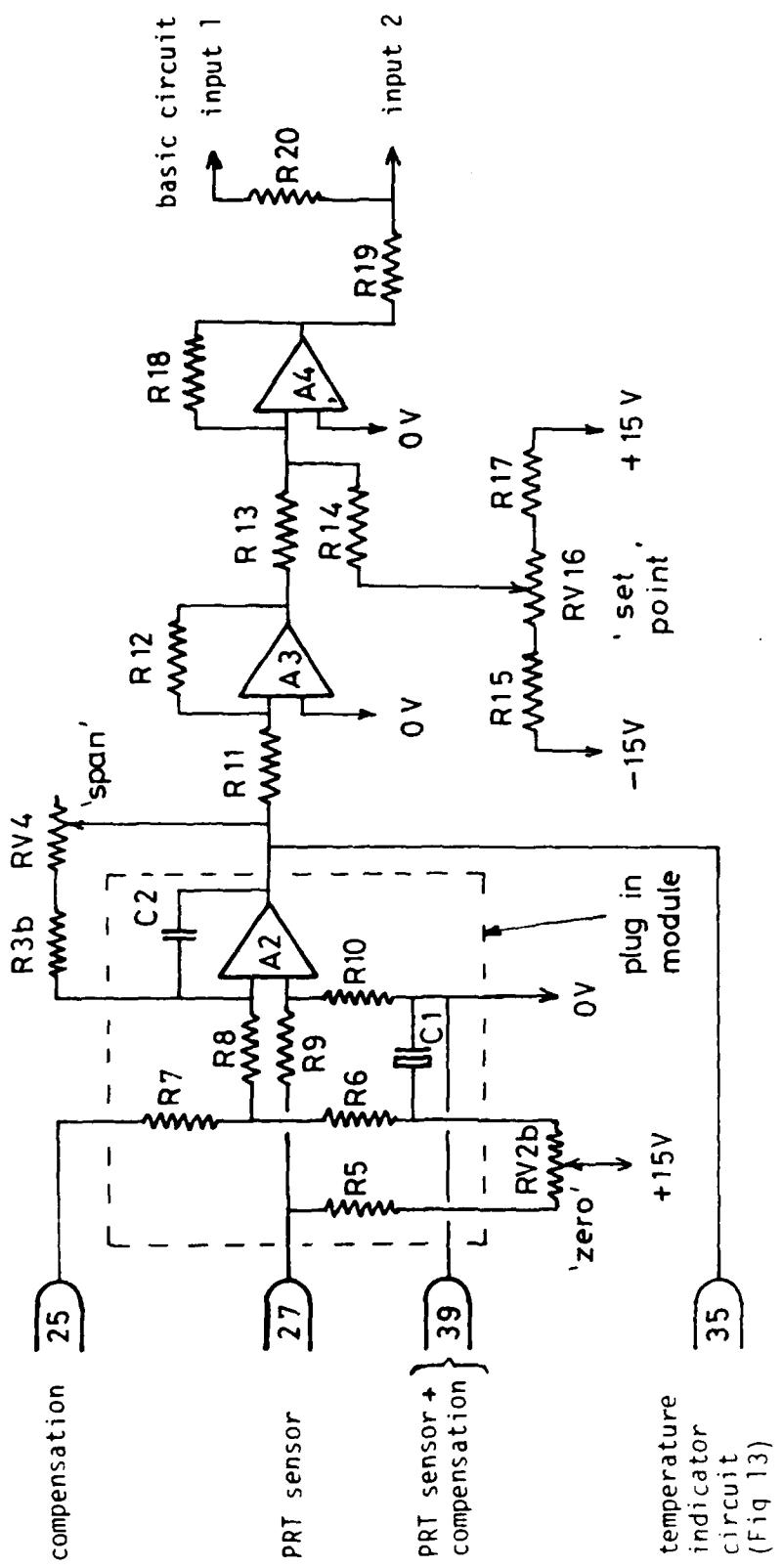
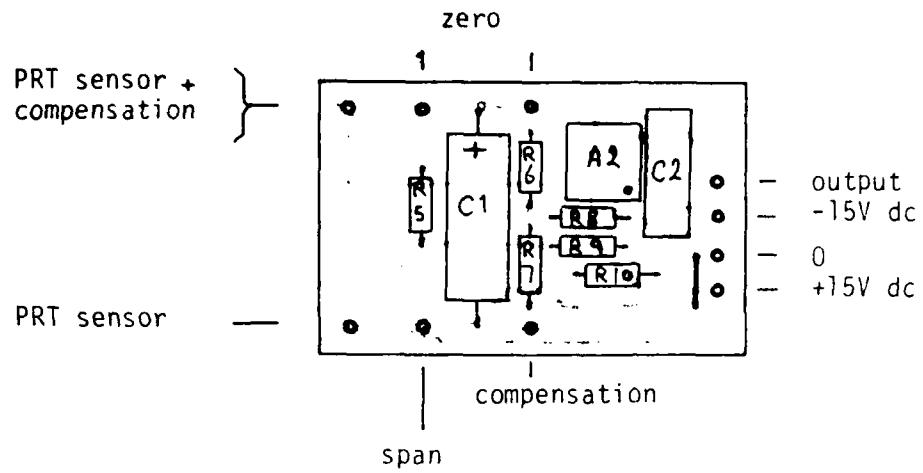
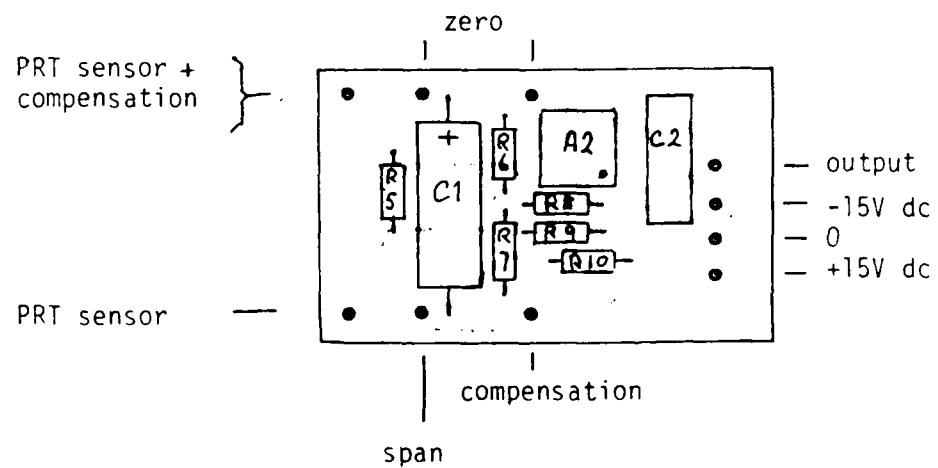


Fig 7 Input circuit for a PRT sensor

Fig 8



Issue A



Issue B

Fig 8 PRT Bridge amplifier PCB layout

Fig 9

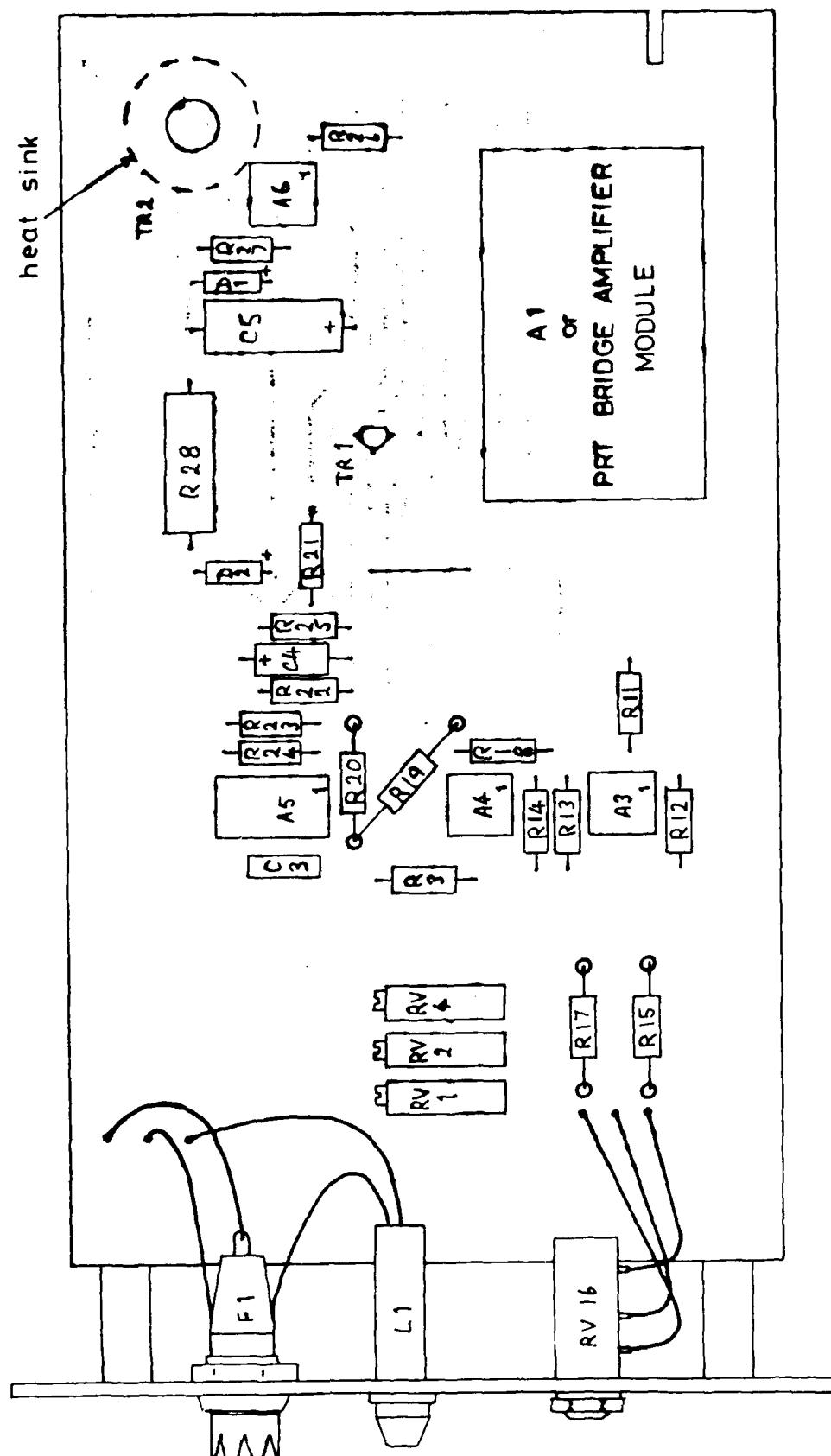


Fig 9 Measurement and control module layout - pcb Issue A

Fig 10

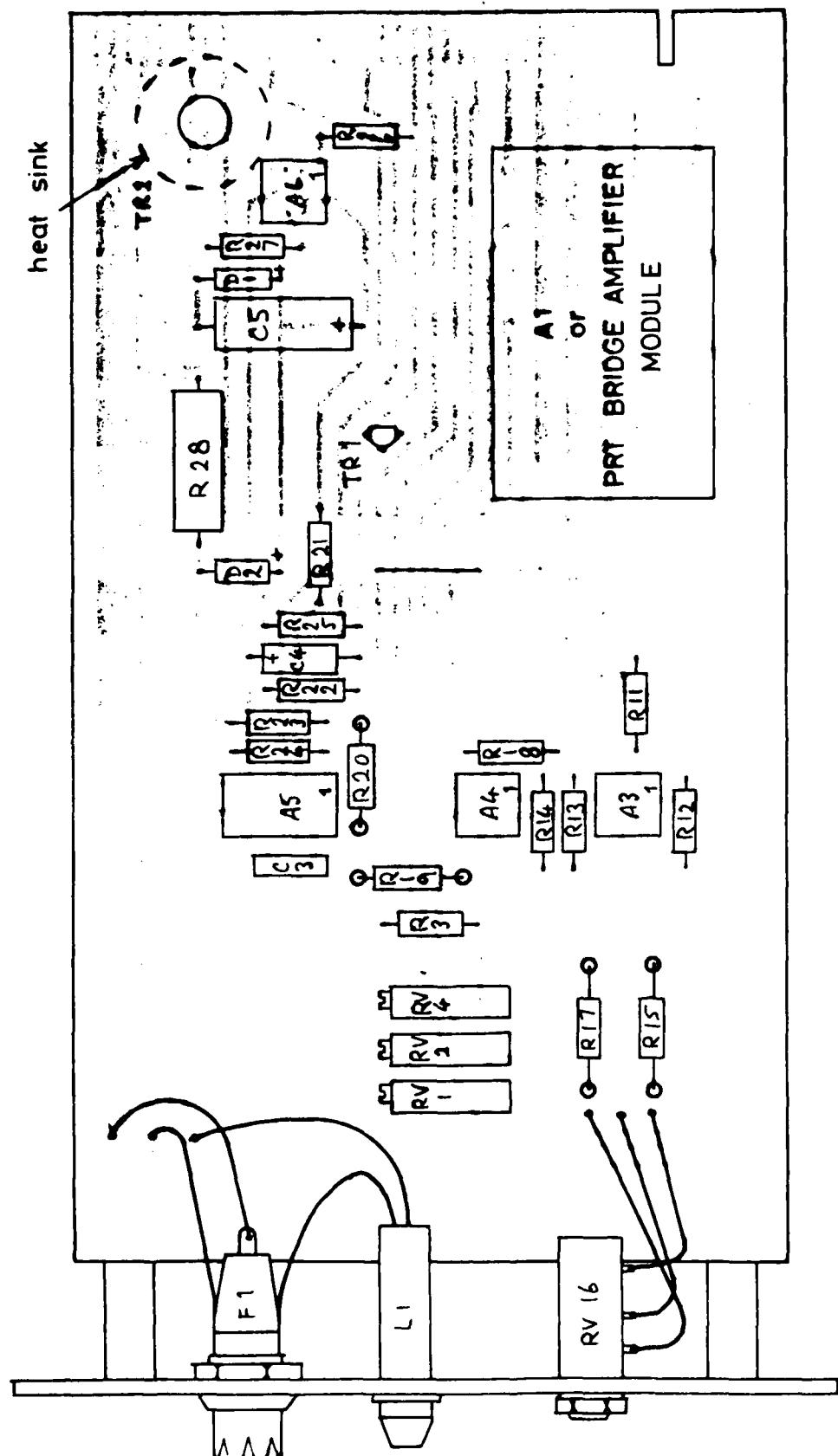


Fig 10 Measurement and control module layout - pcb Issue C

Fig 11

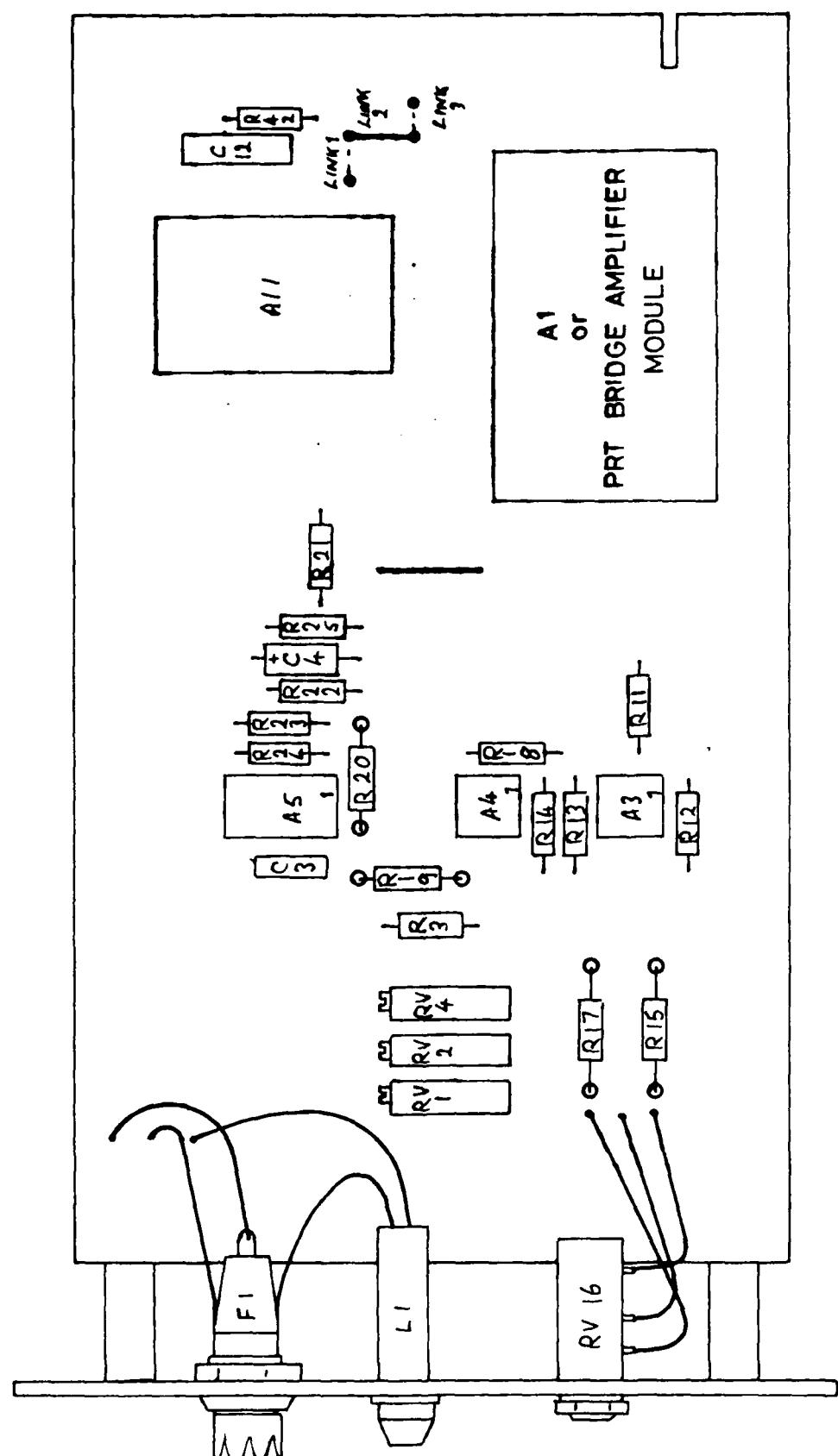


Fig 11 Measurement and control module layout - pcb Issue E

Fig 12

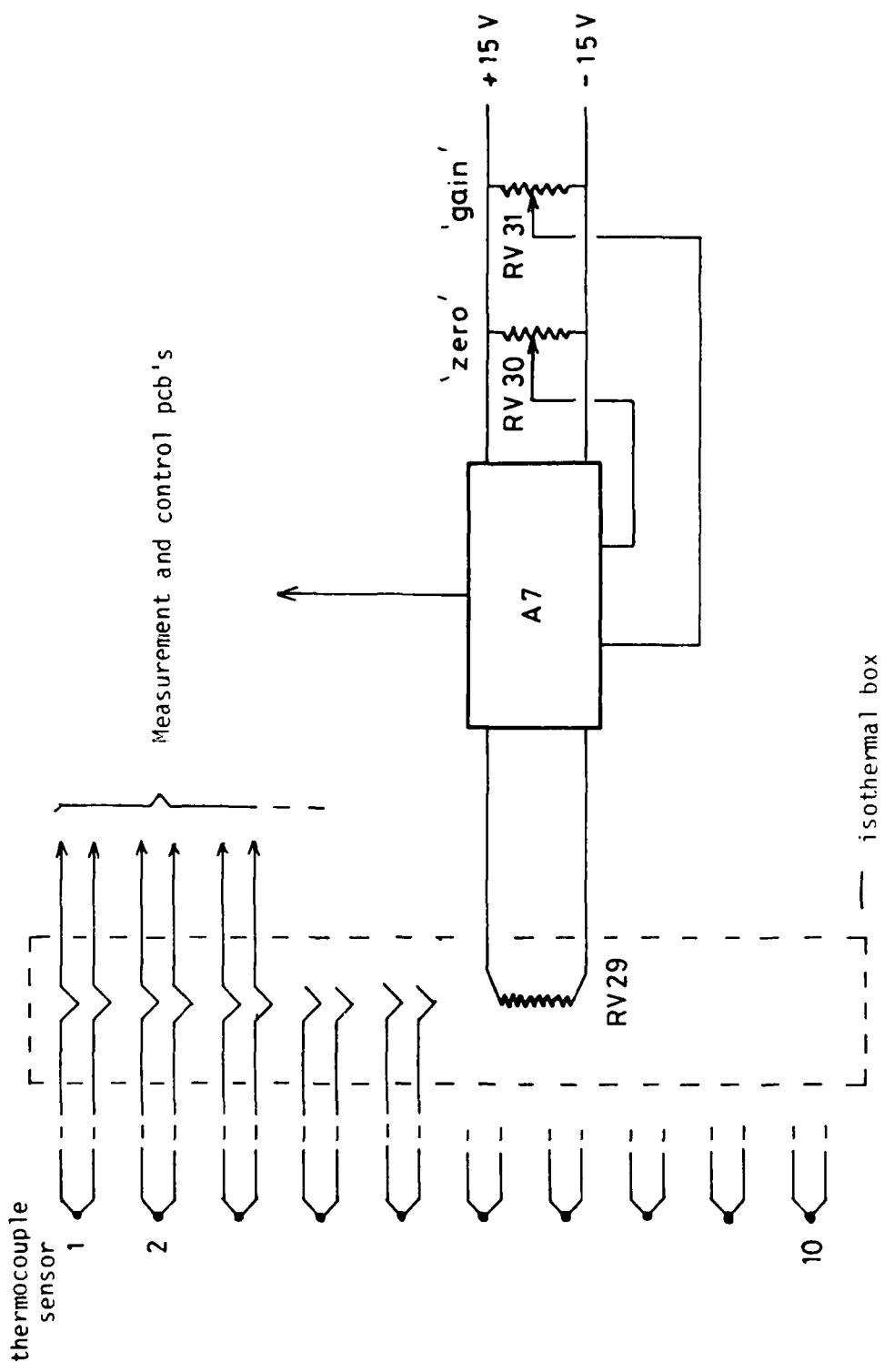


Fig 12 Cold junction compensation circuit

Fig 13

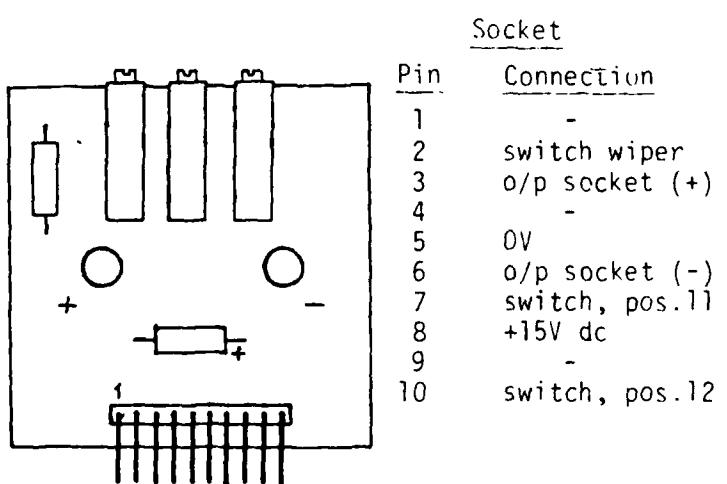
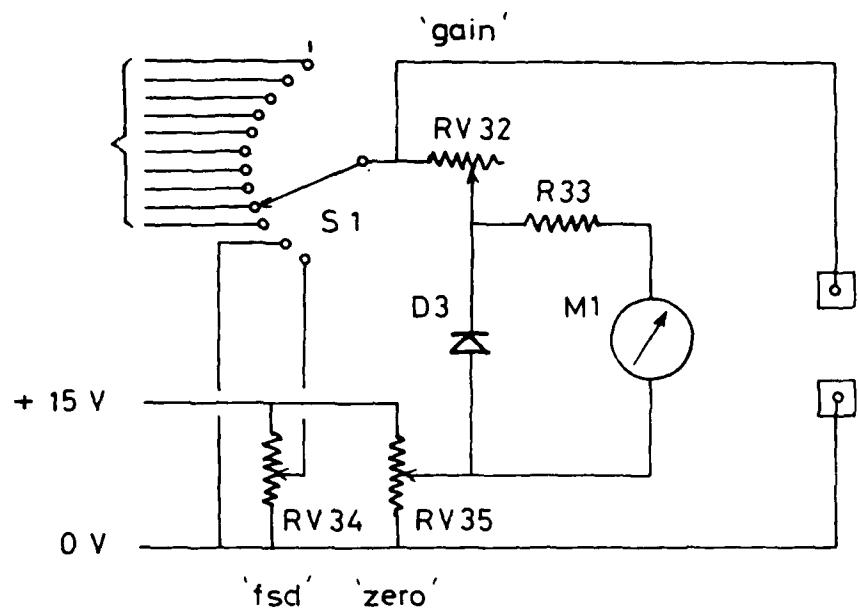


Fig 13 Temperature indicator circuit and pcb layout

Fig 14

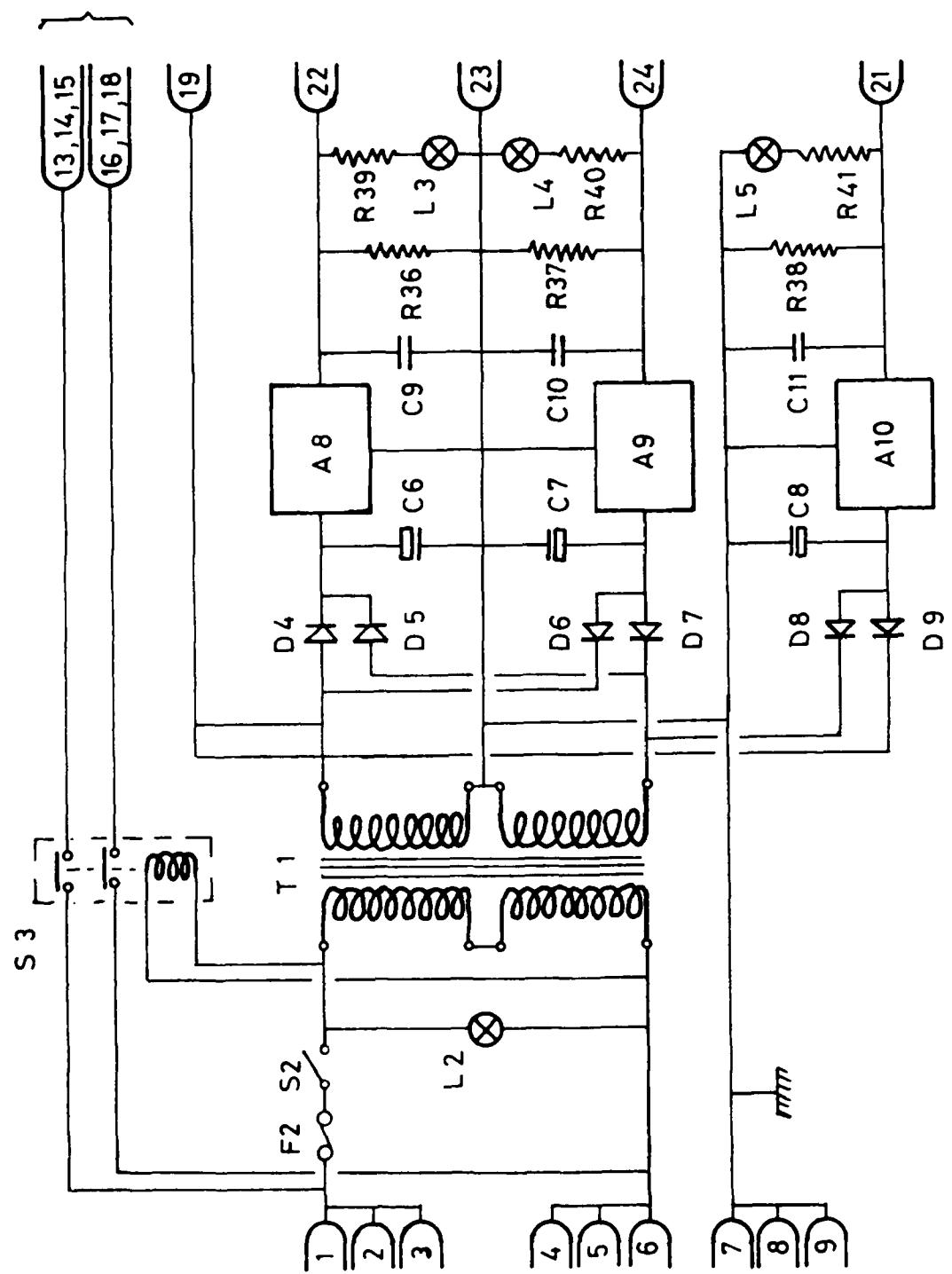


Fig 14 Power supply unit circuit

Fig 15

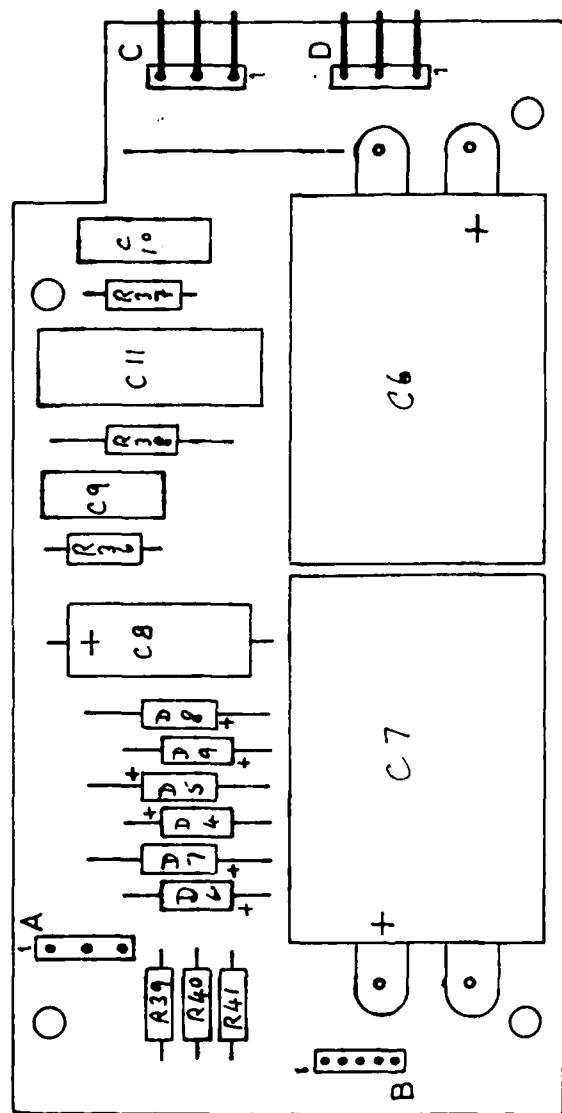


Fig 15 Power supply unit pcb layout

FIG 16

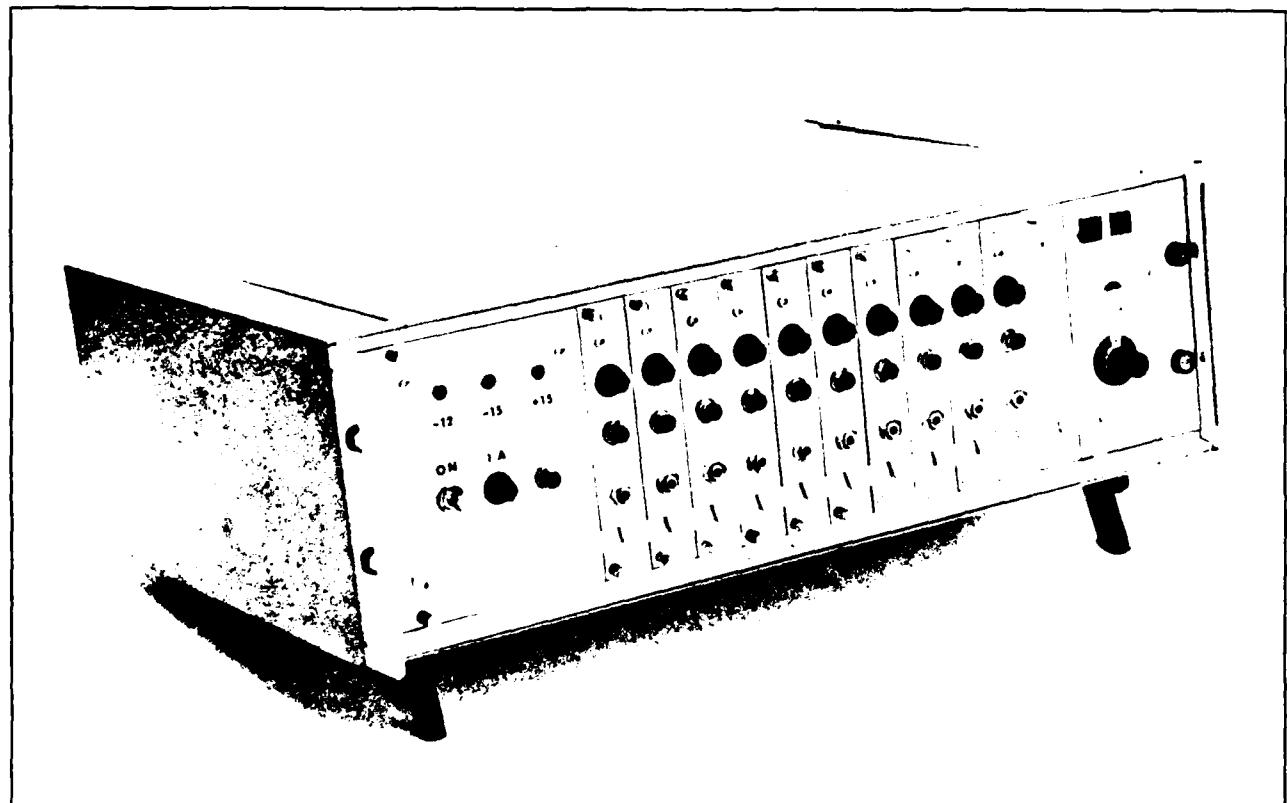


Fig 16 The 10 channel temperature controller

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNCLASSIFIED UNLIMITED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

1. DRIC Reference (to be added by DRIC)	2. Originator's Reference RAE TM P 1026	3. Agency Reference N/A	4. Report Security Classification/Marking UNCLASSIFIED UNLIMITED
5. DRIC Code for Originator 7674300E	6. Originator (Corporate Author) Name and Location Royal Aircraft Establishment, Pyestock, Hants, UK		
5a. Sponsoring Agency's Code N/A	6a. Sponsoring Agency (Contract Authority) Name and Location N/A		
7. Title A ten channel temperature controller			
7a. (For Translations) Title in Foreign Language			
7b. (For Conference Papers) Title, Place and Date of Conference			
8. Author 1. Surname, Initials Lister, D.H.	9a. Author 2	9b. Authors 3, 4	10. Date May 1984 Pages 45 Refs. 2
11. Contract Number N/A	12. Period N/A	13. Project	14. Other Reference Nos.
15. Distribution statement (a) Controlled by – (b) Special limitations (if any) –			
16. Descriptors (Keywords) Temperature control.		(Descriptors marked * are selected from TEST)	
17. Abstract A modular ten channel temperature controller has been designed for use with modestly rated loads (<600 W). Versions using thermocouple and platinum resistance thermometer temperature sensors have been built and their performance characteristics determined. An option for driving higher power loads is also available.			

END

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